



# Cost-effectiveness analysis of single-use negative pressure wound therapy dressings (sNPWT) to reduce surgical site complications (SSC) in routine primary hip and knee replacements

Leo M. Nherera, MSc <sup>1</sup>; Paul Trueman, MA<sup>1</sup>;  
Sudheer L. Karlakki, MD FRCS(Ed) FRCS (GI), FRCS (Tr & Orth) MSc<sup>2</sup>

1. Smith & Nephew Advanced Wound Management, Hull, United Kingdom,  
2. Consultant Orthopaedic Surgeon, Robert Jones and Agnes Hunt Orthopaedic NHS Hospital Foundation Trust, Gobowen, Oswestry, SY10 7AG

## Reprint requests:

Leo M. Nherera, Health Economics  
Manager, Smith & Nephew, Global Market  
Access, 101 Hessle Road, Hull HU3 2BN,  
United Kingdom.  
Tel: +44 (0)1482673185;  
Fax: +44 (0)1482328326  
Email: leo.nherera@smith-nephew.com

Manuscript received: September 30, 2016  
Accepted in final form: February 27, 2017

DOI:10.1111/wrr.12530

This is an open access article under the terms of the Creative Commons Attribution-NonCommercial License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited and is not used for commercial purposes.

## ABSTRACT

We sought to evaluate the cost-effectiveness of single-use negative pressure wound therapy in patients undergoing primary hip and knee replacements using effectiveness data from a recently completed non-blinded randomized controlled trial. A decision analytic model was developed from UK National Health Service perspective using data from a single-centre trial. 220 patients were randomized to treatment with either single-use negative pressure wound therapy or standard care i.e., film dressings of clinician choice and followed for 6 weeks. Outcomes included dressing changes, length of stay, surgical site complications, cost and quality adjusted life years. The randomized controlled trial reported a reduction in dressing changes ( $p = 0.002$ ), SSC ( $p = 0.06$ ) and LOS ( $p = 0.07$ ) in favor of single-use negative pressure wound therapy compared with standard care. The model estimated 0.116 and 0.115 QALY gained, 0.98 and 0.92 complications avoided for single-use negative pressure wound therapy and standard care, respectively. The cost/patient was £5,602 (\$7,954) and £6,713 (\$9,559) for single-use negative pressure wound therapy and standard care respectively resulting in cost-saving of £1,132 (\$1,607) in favor of single-use negative pressure wound therapy. Greater savings were observed in subgroups of higher risk patients with BMI  $\geq 35$  and ASA  $\geq 3$  i.e., £7,955 (\$11,296) and £7,248 (\$10,293), respectively. The findings were robust to a range of sensitivity analyses. In conclusion, single-use negative pressure wound therapy can be considered a cost saving intervention to reduce surgical site complications following primary hip and knee replacements compared with standard care. Providers should consider targeting therapy to those patients at elevated risk of surgical site complications to maximize efficiency.

Postoperative surgical site infection (SSI) is the most common post-operative complication, occurring in up to five percent of all patients undergoing surgery.<sup>1</sup> SSI occurs in 0.7% and 0.6% of patients undergoing orthopaedic surgery i.e., in total hip arthroplasty (THA) and total knee arthroplasty (TKA), respectively,<sup>2</sup> this information is limited to in-hospital and readmissions for surgical site infection. The true incidence of surgical site infection in the community following discharge from the hospital is largely unknown. We have a reasonable estimation of wound complications based on the patient reported outcome measures (PROMS) data published in the National Joint Registry Report, however this information may be exaggerated for two reasons, firstly the PROMS questionnaire return rate is less than 40% and secondly those choosing to return the PROMS questionnaire may be influenced to do so as a result of an adverse outcome (responder bias).

ASA	American Society of Anaesthesiologists
BMI	Body mass index
CD	Crohn's Disease
CEAC	Cost-effectiveness acceptability curves
HRQoL	Health related quality of life
ICER	Incremental cost-effectiveness ratio
LOS	Hospital length of stay
NHS	National Health Service
NICE	National Institute for Health and Care Excellence
NPWT	Negative pressure wound therapy
PROMS	Patient reported outcome measures
QALY	Quality adjusted life years
RCT	Randomized controlled trial
sNPWT	Single-use negative pressure wound therapy dressings
SSC	Surgical site complications
SSI	Surgical site infection

It's commonly agreed that surveillance data based on hospitalization and readmission alone is likely to be an underestimate.<sup>3</sup> Nevertheless the sequelae of SSI can lead to significant human and economic impacts, such as longer hospital lengths of stays, increased resources used for patient care, and reduction in the health related quality of life (HRQoL).<sup>4</sup> In the United Kingdom (UK), hospital length of stay (LOS) is typically doubled and additional per-patient median costs of £3,214 and £2,356 attributable to SSI are reported for hip and knee procedures, respectively.<sup>4</sup> In the US LOS is reportedly increased by 9.5 days and mean additional costs due to SSI are estimated to be in the region of \$15,129 per orthopaedic admission.<sup>5</sup> Furthermore a study by Poultsides<sup>6</sup> on in-hospital SSI after primary hip and knee arthroplasty reports that total treatment costs for patients that experienced a SSI were about double that of patients without SSI.

Negative pressure wound therapy (NPWT) has been used for many years for the treatment of chronic wounds, such as leg ulcers and bed sores and its effectiveness is established.<sup>7</sup> More recently, NPWT use has been extended to acute wounds where it is used prophylactically following surgery to prevent surgical site complications (SSC). However, evidence supporting the clinical effectiveness of NPWT has previously been confined to large non-portable devices. Today, single-use NPWT devices (sNPWT) capable of delivering similar functionality to traditional NPWT devices are available. Such devices are smaller and more portable, allowing for increased mobility compared with traditional NPWT devices, which makes them particularly suitable for post-operative use. The clinical evidence reporting favorable outcomes from these small portable sNPWT devices, such as PICO<sup>®</sup> (Smith & Nephew Healthcare Ltd, Hull, UK) is accumulating rapidly. Systematic reviews by Hyldig et al.<sup>8</sup> and Karlakki et al.<sup>9</sup> concluded that sNPWT was effective in reducing SSI following surgery.

A recent randomized controlled trial (RCT) by Karlakki et al.<sup>10</sup> concluded that sNPWT (PICO<sup>®</sup>) was clinically effective in reducing post-operative wound complications following primary hip and knee replacements. The study found that sNPWT patients experienced a significant reduction in exudate volume and the number of patients with the highest volume of exudate ( $p = 0.007$ ). A fourfold reduction in wound complications, 2.0% vs. 8.4% favoring sNPWT was also reported ( $p = 0.06$ ). Although a non-significant reduction in LOS was found in the intention to treat analysis, 3.8 days (95% CI, 3.5–4.2) for sNPWT compared with 4.7 days (95% CI, 3.8–6.4) for the SC group ( $p = 0.07$ ), patients with American Society of Anaesthesiologists (ASA) score  $\geq 3$  and body mass index (BMI)  $\geq 35$  were determined by recursive partitioning analysis most likely to benefit from sNPWT ( $p = 0.02$ ). The purpose of the present analysis is to evaluate the cost-effectiveness of sNPWT in all patients and sub-groups of patients at elevated risk of complications undergoing elective primary hip and knee replacement using the outcomes data derived from randomized controlled trials.

## MATERIALS AND METHODS

Data for this economic analysis were derived from a clinical trial of 220 consecutively enrolled adults aged 18 years

or older scheduled to undergo routine hip and knee replacement Karlakki et al.<sup>10</sup> The trial was non-blinded, due to obvious visual differences between the treatment and standard care dressings. It was conducted between October 2012 and October 2013 and patients were followed for 6 weeks after surgery. Baseline characteristics of all patients and the sub-groups included in the original RCT analysis is shown in Table 1.

A decision model was used to simulate the expected cost and benefits of sNPWT and standard care in accordance with best practice standards for economic evaluations i.e., The Consolidated Health Economic Evaluation Reporting Standards.<sup>11</sup> The perspective adopted was that of the healthcare payer in the UK. The outcomes assessed were surgical site complications and quality adjusted life years (QALYs) and LOS. The expected complications with standard care were taken from the Karlakki et al. RCT.<sup>10</sup> These baseline data were then adjusted to reflect the expected reduction in complications and LOS reported in the same RCT observed in patients treated with sNPWT.

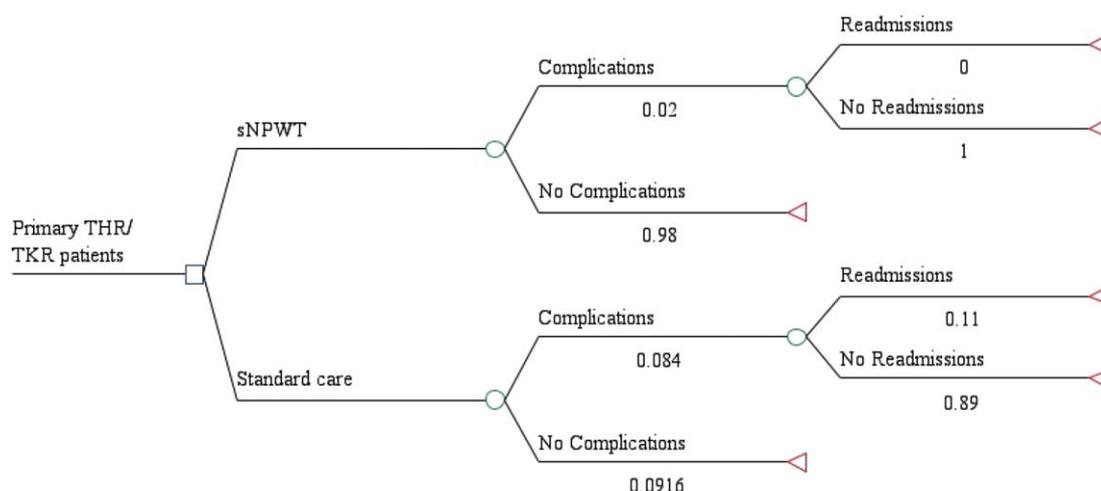
The economic model adopted a similar time horizon as the RCT of 6 weeks post-operatively, which was deemed sufficient follow-up to capture the majority of SSI and their associated impact on resource use and outcomes. Given the short time horizon of less than 1 year, no discounting was applied to either costs or outcomes.

**Table 1.** Showing the distribution and baseline patient characteristics between the sNPWT and standard care groups used for the intention to treat analysis of the RCT

	sNPWT Mean (SD) or n (%)	Standard care Mean (SD) or n (%)
Patients	102	107
Female	53 (52%)	52 (49%)
Male	49 (48%)	55 (51%)
Age	69.0 (9.0)	69.2 (9.0)
Joint		
Hip	53 (52%)	6 (59%)
Knee	49 (48%)	44 (41%)
BMI	30.1 (5.0)	28.4 (4.6)
Obesity (BMI>35)	17 (17%)	9 (8%)
ASA score	n=94	n=104
1	23 (24%)	24 (23%)
2	60 (64%)	69 (66%)
3	11 (12%)	11 (11%)
Comorbidities		
Number of comorbidities	1.9 (1.5)	1.7 (1.5)
Any	80 (78%)	80 (75%)
Morbid obesity (BMI>40)	3 (3%)	1 (1%)
Smoking (current or previous)	14 (22%)	13 (22%)
Diabetes	5 (5%)	12 (11%)

Source: Karlakki et al.<sup>10</sup>

Abbreviations: sNPWT, single use negative pressure wound therapy; BMI, body mass index; SD, standard deviation.



**Figure 1.** The decision model for the cost-effectiveness of sNPWT compared with standard care in patients undergoing primary total hip and knee replacement. [Color figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

Furthermore, mortality was not modelled as the short time-horizon was considered too short to discern the impact of intervention on mortality. The schematic representation of the model is shown in Figure 1.

Two measures of benefits were used in the model; firstly, incremental complications avoided for the cost-effectiveness analysis and QALYs for the cost utility analysis. A QALY is a measure of disease burden, which takes into account the quantity or length of life and quality of life generated by healthcare interventions and is used in assessing the value for money of a medical intervention. A year of perfect health is worth 1 QALY and a year of less than perfect health is worth less than 1 while death is considered to be equivalent to 0.

Data on health related quality of life were obtained from the NICE clinical guideline on surgical site infections 2008.<sup>12</sup> The study cited in the guideline reported on the impact of orthopaedic surgical-site infections (SSIs) on quality of life, length of hospitalization, and costs. Cases of orthopaedic SSIs were prospectively identified by infection control professionals, and matched controls were selected from the entire cohort of patients undergoing orthopaedic surgery who did not have an SSI. Quality of life was measured using the short form of a questionnaire containing 36 items (SF-36) 1 year post surgery. Results of the SF-36 were then converted to utility values using a published algorithm.<sup>13</sup> Data for all the clinical input parameters and quality of life used in the model is shown in Table 2.

Resource use was not based on the treatment regimen used in the trial to enhance the generalizability of the cost-effectiveness results beyond the single centre where the RCT was performed. Costs were therefore derived from standard cost references with resource utilization valued in £(2015/16). The cost of the intervention (sNPWT) was obtained from the national Drug Tariff.<sup>14</sup> We acknowledge this cost is likely to be higher than the discounted price that the hospitals actually pay through discounted prices given to NHS bulk purchasing; therefore we varied the cost in sensitivity analysis. The model applied the cost of

one sNPWT device, which is designed to last for 7 days and is supplied with two dressings. In the sensitivity analysis we assumed patients received two sNPWT dressings to assess changes in expected total costs.

For inpatient care we used an average of NHS reference costs<sup>15</sup> for the following medical diagnosis related groups (DRGs) HN13 B-H and HN23 A-E for hips and knees to establish the cost of hospitalization of all patients who had surgery. The mean cost was £6,725 and lower and upper costs were £3,863 and £8,280, respectively. The model assumed that costs of standard care dressings and nursing costs were all included in the DRG costs.

All patients were on an enhanced recovery programme and therefore were managed in the community once they were discharged. After discharge patients were all contacted by phone and were all prescribed low molecular weight heparin (LMWH), consequently this was not costed as the costs were assumed to be the same across the two interventions. Furthermore, all patients were seen at 6 weeks post-surgery in the consultant led follow-up clinic as per the routine practice and this cost was also excluded as all patients incurred the same cost. For patients who experienced complications, we assumed they had two visits to the GP and received one prescription of antibiotics. The cost of a GP visit was taken from Unit Costs and Social Care 2015–2016<sup>16</sup> while costs of oral antibiotics (assumed to be flucloxacillin 500 mg QDS or if allergic to penicillin erythromycin 500 mg QDS) were taken from the Drug Tariff.<sup>14</sup> One of the most common side effects of surgery is pain. However, the model did not incorporate the costs of managing pain as it was assumed all patients will be on pain medication following surgery. Table 3 shows the cost data that was used in the model.

We did not cost the additional LOS due to infection for the patients that developed complications in the hospital making the model conservative since two patients in the standard care group developed complications as inpatients and needed surgical washout. Furthermore readmission was not included in the base case model. The study by Karlakki et al.<sup>10</sup> showed that one patient of the nine

**Table 2.** Baseline model inputs and treatment effect

<b>* Baseline complications in the general population</b>					
	Mean	Alpha	Beta	Number	Distribution
sNPWT	0.020	2	100	102	Beta
SC	0.084	9	98	107	Beta
Readmission with SC	0.111	1	8	9	Beta
<b>* Sub groups complication rates</b>					
	Mean	Lower value	Upper value	SE	Distribution
BMI $\geq$ 35	4.500	1.100	16.000	0.683	Log normal
ASA $\geq$ 3	8.300	2.500	27.900	0.615	Log normal
<b>* Reduction in complications due to sNPWT</b>					
Overall complication rates	0.190	0.020	0.950	0.985	Log normal
<b>* Length of hospital stay (LOS)</b>					
Length of stay sNPWT	3.800	3.500	4.200	0.047	Log normal
Length of stay SC	4.700	3.800	6.400	0.133	Log normal
<b>* Capped length of hospital stay (LOS) (removing LOS outliers)</b>					
Length of stay sNPWT	3.8	3.5	4.3	0.053	Log normal
Length of stay SC	4.1	3.8	4.7	0.054	Log normal
<b>Excess LOS for sub groups</b>					
BMI Excess LOS*	5.900	2.800	24.000	0.548	Log normal
ASA class*	7.500	4.000	28.200	0.498	Log normal
<b>** Reduction in LOS for ASA</b>					
Length of stay sNPWT	4.550	2.000	9.000	0.384	Log normal
Length of stay SC	10.450	2.000	12.900	0.476	Log normal
<b>** Reduction in LOS for BMI<math>&gt;</math>35</b>					
Length of stay sNPWT	3.820	2.000	9.000	0.384	Log normal
Length of stay SC	9.890	2.000	49.800	0.820	Log normal
<b>Quality of life data used in the model</b>					
QALY with SS1 <sup>12</sup>	0.570	0.510	0.640	0.034	Beta
QALY with no SS1 <sup>12</sup>	0.640	0.570	0.710	0.036	Beta

\*Data obtained from Karlakki trial<sup>10</sup>.

\*\*Data obtained from a post-hoc analysis of the Karlakki trial.

Abbreviations: GP, general practitioner; SE, standard error; BMI, body mass index; ASA, American Society of Anesthesiologists; SS1, surgical site infections; LOS, length of stay; SC, standard care; sNPWT, single use negative pressure wound therapy.

**Table 3.** Cost data used in the model

Component	Mean	Lower	Upper	SE	Distribution
Inpatient cost orthopaedic	£1,431	£822	£1,762	£239.71	Gamma
Nurses cost per hour	£37.26	£31.65	£41.59	£2.54	Gamma
Dressings (sNPWT)	£144	£120	£150	£119	Gamma
WF01A non-admitted face to face attendance, follow-up trauma & orthopaedics	£91	£56	£115	£101	Gamma
GP Per patient contact lasting 11.7 minutes	£37				Not varied
Antibiotics (flucloxacillin 500 mg tablets)	£2.20				Not varied
Antibiotics (erythromycin 500 mg tablets)	£10.78				Not varied

Abbreviations: SE, standard error; sNPWT, single use negative pressure wound therapy.

**Table 4.** Deterministic results; sNPWT compared with standard care

Intervention	Costs	Complications avoided	QALYs	Cost difference	Complication difference	QALY difference
Standard care	£6,713 (\$9,559)	0.92	0.115			
sNPWT	£5,602 (\$7,954)	0.98	0.116	−£1,132 (\$1,607)	0.07	0.0014
Probabilistic results; sNPWT compared with standard care						
Standard care	£6,740 (\$9,585)	0.92	0.116			
sNPWT	£5,692 (\$8,083)	0.97	0.117	−£1,049 (\$1,490)	0.059	0.0012

Abbreviations: QALY, quality adjusted life year (s); sNPWT, single use negative pressure wound therapy.

patients who developed complications (11%) was readmitted in the standard care group and none in the sNPWT group making the model even more conservative i.e., biased against sNPWT. In the sensitivity analysis, we tested these two assumptions i.e., included the cost of additional LOS and readmission in the model. More patients managed with sNPWT developed minor blisters (<1 cm) (11%) compared with 1% in the standard care group which were managed by a foam dressing. In the model the cost of managing blisters were excluded as they were deemed to be negligible and the majority of the treatment would be captured in the diagnosis related group case payment.

### Cost-effectiveness analysis

The incremental cost-effectiveness ratio (ICER) is the added cost per additional unit of health, in this model measured in QALYs and complications avoided. This was calculated as the difference between the expected costs divided by the expected difference between the QALYs or complications avoided of sNPWT and standard care over the 6-week time horizon. To determine if the intervention is cost-effective, the ICER is compared with the maximum willingness to pay of the healthcare payer, in this case assumed to be the threshold set by UK payer body The National Institute for Health and Care Excellence (NICE) of £20,000/QALY. If the calculated ratio is less than what the payer is willing to pay for a unit of health, the intervention is deemed cost-effective. In the results, we report both deterministic and probabilistic results for the base case model. The costs were estimated from the United Kingdom NHS perspective, however we also used the purchasing power parity conversion factor of 1.42 to convert pounds into US dollars (Available at <http://wdi.worldbank.org/table/4.16>, Accessed January 2017).

### Sensitivity analysis

Both deterministic and probabilistic sensitivity analyses were done. Probabilistic sensitivity analysis entails specifying a distribution for each model parameter to represent the uncertainty around the point estimate and then selecting values at random from those distributions using Monte Carlo simulation. Essentially, this means the uncertainty around multiple input assumptions can be tested simultaneously, distinct from one-way sensitivity analysis which allows uncertainty around single inputs to be tested individually. The lognormal distribution was implemented to

capture the uncertainty surrounding the treatment effect; the gamma and beta distributions were used to capture the uncertainty in cost and utility values, respectively. Two-thousand simulations were conducted.

A cost-effectiveness plane is also presented which is divided into four quadrants by the origin, i.e., south east (SE), north east (NE), south west (SW) and North West (NW) with each quadrant having a different implication for economic evaluation.<sup>17</sup> The vertical axis divides the plane according to incremental cost (positive above, negative below zero) and the horizontal axis divides the plane according to incremental effect (positive to the right, negative to the left). Cost-effectiveness acceptability curves (CEACs) are then calculated by plotting the proportion of cost and effects pairs that are cost effective for a given value that the payer is willing to pay. Thus the CEAC expresses the likelihood the cost-effectiveness estimate reflects a cost-effective intervention based on the existing evidence.

One-way sensitivity analyses were conducted by varying some of the parameters in the model to address the impact of possible uncertainty in the best information available on clinical benefits and treatment costs. Each key parameter was alternately assigned a low and high value and the deterministic cost-effectiveness results using this value were recorded. Key parameters varied were costs of hospital stay, cost of sNPWT and cost of readmissions. Baseline data were varied across the 95% confidence interval reported in the trial or lower and upper values reported in literature. Length of stay in the standard of care group had a range of 2–61 days affected by two wound related outliers. A sensitivity analysis was performed arbitrarily capping LOS to 13 days (3rd longest LOS in the control group, see Table 2 for data used). In addition we performed subgroups analysis considering BMI  $\geq 35$  and ASA score  $\geq 3$ . These were deemed as variables that affect the prognosis of patients undergoing hip and knee surgery as was reported in analysis.<sup>18</sup>

## RESULTS

The total mean costs for patients in the sNPWT group were lower than patients in the SC group. The use of sNPWT was associated with more QALYs and fewer wound related complications compared with the use of SC. Overall, the use of sNPWT is technically a dominant strategy compared to SC, i.e., sNPWT costs less and results in

**Table 5.** Sensitivity analysis demonstrating the influence of parameter uncertainty on the expected mean cost difference between sNPWT and standard care

Input parameter	Lower value used	Upper value used
Readmissions (included and excluded)	-£1,132 (-\$1,607)	-£7,750 (-\$11,005)
Capped mean LOS for standard care (4.7 vs. 4.1 days)	-£1,132 (-\$1,607)	-£348 (-\$494)
Mean cost of hospital LOS-lower (£822 & £1,762)	-£592 (-\$841)	-£1,424 (-\$2,022)
Treatment impact of sNPWT on LOS (-0.2 and 2.5 days)	-£1,413 (-\$2,007)	-£1,132 (-\$1,607)
Number of sNPWT used (1 and 2)	-£1,132 (-\$1,607)	-£990 (-\$1,406)
Treatment impact of sNPWT on complications (OR 0.02 & 0.95)	-£1,149 (-\$1,632)	-£1,053 (-\$1,495)
Cost of sNPWT (£120 & £150)	-£1,155 (-\$1,640)	-£1,126 (-\$1,599)
Risk of SSC complications with SC (0.067 & 0.101)	-£1,134 (-\$1,610)	-£1,129 (-\$1,603)

Abbreviations: LOS, length of stay; SC, standard care; sNPWT, single use negative pressure wound therapy; OR, odds ratio; SSC, surgical site complications.

better clinical outcomes. Table 4 shows both deterministic and probabilistic results.

**Sensitivity analysis**

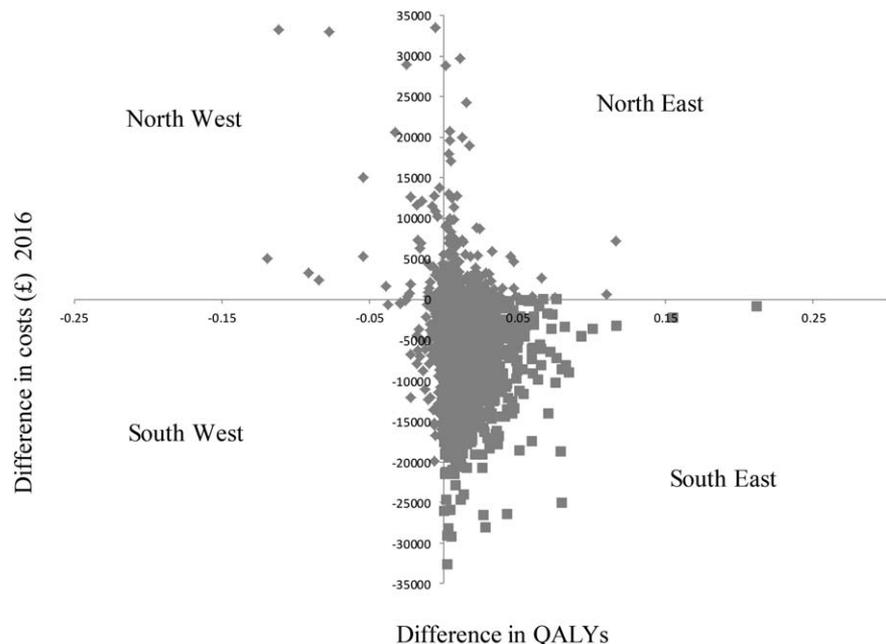
The output of a series of one-way sensitivity analyses is displayed in Table 5. The results of the analyses illustrate the mean incremental costs of sNPWT compared with SC. Negative costs shows that sNPWT is cost-saving compared with SC. The base-case value was -£1,132 (-\$1,607) which means sNPWT saves £1,132 (\$1,607) per patient in this patient population. The model remained cost-saving for all inputs that were changed as shown in Table 5 where all the cost differences are below £0.

Results from the probabilistic sensitivity analysis are shown on the cost-effectiveness plane in Figure 2. The cost-effectiveness plane shows that both incremental cost and incremental QALY estimates are associated with little

uncertainty as the majority of samples are located in the south east quadrant. The cost-effectiveness acceptability curves (CEACs) communicate the probability for an intervention to be cost-effective for a range of willingness-to-pay thresholds (£/QALY). CEACs suggest that the sNPWT is 91% cost-effective in all analyses for the willingness-to-pay threshold range of £20,000 recommended by NICE<sup>17</sup> and in 79% of the simulations will be dominating standard care i.e., 79% of the simulations fall in the south east quadrant shown in Figure 2.

**Subgroup analysis**

Incidence of SSI and subsequent LOS is affected among other factors by BMI and ASA grade.<sup>10</sup> Therefore, in the sensitivity analysis we separately compared the cost-effectiveness of sNPWT and standard of care for patients with BMI ≥ 35 and ASA ≥ 3. Having an ASA ≥ 3



**Figure 2.** Scatter plot showing the incremental costs and QALYs of sNPWT and standard care in primary hip and knee replacement.

**Table 6.** Sub-group analysis ASA  $\geq 3$  and BMI  $\geq 35$ , deterministic results, sNPWT compared with standard care, mean costs, outcomes

Intervention	Costs	Complications avoided	QALYs	Cost difference	Complication difference	QALY difference
Sub-group analysis ASA $\geq 3$						
Standard care	£17,520 (\$24,878)	0.30	0.103			
sNPWT	£10,272 (\$14,586)	0.87	0.114	-£7,248 (-\$10,293)	0.57	0.0114
Sub-group analysis BMI $\geq 35$						
Standard care	£15,202 (\$21,587)	0.62	0.109			
sNPWT	£7,247 (\$10,291)	0.93	0.115	-£7,955 (-\$11,296)	0.31	0.0062

Abbreviations: sNPWT, single use negative pressure wound therapy; QALY, quality adjusted life year; BMI, body mass index; ASA, American Society of Anesthesiologists.

increases the risk of SSI/complications by 8.3 while a BMI  $\geq 35$  increases complications by 4.5 compared with the general population.<sup>10</sup> sNPWT was shown in the same study to reduce LOS by 5.91 days for ASA  $\geq 3$  and by 6.1 days in those with a BMI  $\geq 35$ . The difference was not statically significant (data from post-hoc analysis of the RCT data by Karlakki). Tables 6 shows the deterministic results of ASA  $\geq 3$  and BMI  $\geq 35$  sub-groups. In all cases sNPWT was cost saving, with the results showing cost-savings of £7,955 (\$11,296) and £7,248 (\$10,293) per patient for those with BMI  $\geq 35$  and ASA  $\geq 3$ , respectively.

## DISCUSSION

The demand for cost-effectiveness evidence has increased for many reasons. Prime among these are shrinking health care budgets, growing patient populations and the practice of value-based treatment decisions. Such decisions do not focus on the acquisition costs of health care technologies in isolation; rather, they integrate these within the total cost of a treatment process. These total costs of care are then balanced against the entirety of clinical outcomes of interest measured over a discrete period of time to result in a cost-effectiveness analysis. We built a decision tree to investigate the value of sNPWT compared with standard care in the prevention of complications following total hip and knee replacement surgery using clinical data from a recent RCT by Karlakki and his colleagues.<sup>10</sup>

The use of sNPWT was reported to have delivered a fourfold reduction in surgical site wound complications and reduced LOS by 1 day compared with SC.<sup>10</sup> The mean cost per patient in the sNPWT group was estimated to be £5,602 (\$7,954), compared with £6,713 (\$9,559) in the SC group. The use of sNPWT was associated with 0.116 QALYs, compared with 0.115 QALYs for the SC group. Overall, the sNPWT strategy was on average, £1,132 (\$1,607) less costly, and was associated with fewer surgical site complications (6 per 100 treated patients) and more QALYs per patient. Probabilistic sensitivity analyses suggest that sNPWT has a 91% probability of being cost-effective with 79% of the simulations finding a dominant result compared with standard care. The result was robust to a range of sensitivity analyses.

Similar results were obtained between the deterministic and probabilistic results for sNPWT compared with standard care. The model suggests that more savings will be made when higher risk patients with an ASA  $\geq 3$  and BMI  $\geq 35$  are targeted. This result is partly explained by the increased baseline risk of complications and associated increase in LOS in these populations compared with the general population. This result should be treated with caution and seen as indicative since the difference in LOS was not statistically significant and had wider confidence intervals. Karlakki et al.<sup>10</sup> showed that patients with a higher ASA  $\geq 3$  and BMI  $\geq 35$  have an 8 and 4.5 fold increase in the risk of complications and above average LOS. This is in line with literature which suggests ASA score and BMI are prognostic factors for complications in patients undergoing total hip and knee replacements.<sup>18</sup>

Economic evaluations are relatively rare in wound care, largely due to an absence of clinical data. To our knowledge, this study is the first comparative economic evaluation of sNPWT in any setting for patients undergoing total hip and knee replacements. We conducted a number of sensitivity analyses and sub-group analyses which all confirmed the benefits of sNPWT in preventing SSC following total hip and knee replacements.

The economic analysis used clinical data derived from a well conducted RCT in which the standard care was determined by individual clinicians. This is one of the strengths of the RCT as it replicates what happens in real-life clinical scenarios where clinicians use various interventions, thus making the results more generalizable. Furthermore, the model adopted a number of conservative assumptions so the projected savings may actually under-estimate the true financial impact. Among patients in the standard care group, 11% of patients who developed complications were readmitted to the hospital and underwent surgical washout compared with none in the sNPWT group, and this was not included in the base case analysis. We note that studies in Crohn's Disease (CD) have had similar findings where patients treated with sNPWT did not experience re-admission following elective surgery for CD compared with those treated with standard care.<sup>19</sup> Including readmission in the present analysis resulted in savings of £7,750 (\$11,005) per patient compared with £1,132 (\$1,607) in the base case. The cost of pain medication was also excluded in the base case analysis, this assumption

however favor standard care group which had many wound related complications. Furthermore, we note that there were few dressing changes in the sNPWT group (1.79  $p=0.002$ ) which suggests that savings could be more when staff time is taken into account, time which could be used for other clinical or non-clinical activities.

There are some limitations associated with this analysis. The transferability of clinical and economic outcomes is an important issue in health economic evaluation.<sup>20</sup> Previous research has demonstrated substantial differences in both treatment patterns and the nature of cost savings across countries owing to the differences in healthcare systems. Reimbursement systems, relative prices, and treatment practices, are important issues that vary from country to country. Furthermore, our model is based on clinical data that comes from a single centre RCT. While the study investigators were allowed to select the standard care of their choice, this was largely a single centre practice which may not be representative of standard care used across different locations in the UK or other healthcare systems in the world. Decision-makers in other healthcare systems should therefore investigate the cost-effectiveness of sNPWT products in their own settings. We also note that there was an increased incidence of minor blisters in patients treated with sNPWT compared with those treated with SC, and the model excluded the costs of managing the blisters as they were deemed to be negligible. Occurrence of blisters was dependent on the experience of the clinician and one way of minimizing the blisters is to avoid stretching the dressing by applying it on a flexed joint.

The current study also excluded any costs involved in treating SSC following discharge from the hospital. One study on the costs of SSI care in a primary setting in the UK collected data on<sup>21</sup> SSI patients following colorectal surgery and found that primary care costs amount to about 15% of total SSI costs (on average £1,563 (\$2,219) out of £10,523 (\$14,943) per SSI patient), thus suggesting that the largest part of the SSI cost burden comes from inpatient care. As such, whilst we are confident that we have captured the majority of the resource involved in managing SSC, there is further reason to believe that the findings may under-report the true scale of the savings.

In conclusion, we found sNPWT to be a cost-effective intervention to reduce SSC following total hip and knee replacements. The analysis demonstrated savings of over £1,000 (\$1,420) per patient were associated with a policy of using sNPWT immediately post-operatively in hip and knee replacement surgeries. Sub-group analysis identified even greater savings in patients at elevated risk of surgical site complications. Healthcare providers may wish to consider how such a technology is applied in practice and design protocols that identify those patients at greatest risk of surgical site complications following total joint replacement, such as patients undergoing revision surgery and patients with multiple comorbidities. A targeted approach to adoption such as this will maximize the efficiency, by addressing those patients at greatest risk of complications and excess treatment costs. Prospective research on the costs and outcomes of sNPWT in this patient population is necessary to validate the results of this economic evaluation.

## ACKNOWLEDGMENTS

We like to thank Mr Paul Just, Dr Vicki Strugala and Dr Robin Martin for their comments during the writing of the manuscript.

*Authorship:* Mr L M Nherera; Conducted the economic analysis and writing of the paper.

Mr P Trueman, Double checked the economic analysis and commented on the paper.

Mr S L Karlakki; Advised on clinical aspects of the analysis, contributed to the writing of and commented on the paper.

*Conflict of Interest:* LN and PT are employees of Smith & Nephew, Wound Management Hull, and may own shares of Smith & Nephew. SK has no competing financial interests.

## REFERENCES

1. Smyth ETM, McIlvenny G, Enstone JE, Emmerson AM, Humphreys H, Fitzpatrick F, Davies E, Newcombe RG, Spencer RC, on behalf of the Hospital Infection Society Prevalence Survey Steering Group. Four country healthcare associated infection prevalence survey 2006: overview of the results. *J Hosp Infect* 2008; 69: 230–48.
2. Health Protection Agency. *Protocol for the surveillance of surgical site infection* London: Health Protection Agency, 2011.
3. Hospital Episode Statistics. *Provisional monthly patient reported outcome measures (PROMs) in England: a guide to PROMs methodology*. London: Health and Social Care Information Centre, 2011.
4. Jenks PJ, Laurent M, McQuarry S, Watkins R. Clinical and economic burden of surgical site infection (SSI) and predicted financial consequences of elimination of SSI from an English hospital. *J Hosp Infect* 2014; 86: 24–33.
5. de Lissovoy G, Fraeman K, Hutchins V, Murphy D, Song D, Vaughn BB. Surgical site infection: incidence and impact on hospital utilization and treatment costs. *Am J Infect Control* 2009; 37: 387–97. doi: 10.1016/j.ajic.2008.12.010
6. Poultsides LA, Ma Y, Della Valle AG, Chiu YL, Sculco TP, Memsoudis SG. In-hospital surgical site infections after primary hip and knee arthroplasty—incidence and risk factors. *J Arthroplasty* 2013; 28: 385–9.
7. Vig S, Dowsett C, Berg L, Caravaggi C, Rome P, Birke-Sorensen H, et al. Evidence-based recommendations for the use of negative pressure wound therapy in chronic wounds: steps towards an international consensus. *J Tissue Viability* 2011; 20 (Suppl. 1): S1–S18.
8. Hyldig N, Birke-Sorensen H, Kruse M, Vinter C, Joergensen JS, Sorensen JA, et al. Meta-analysis of negative-pressure wound therapy for closed surgical incisions. *BJS* 2016; 103: 477–86. doi: 10.1002/bjs.10084
9. Karlakki S, Brem M, Giannini S, Khanduja V, Stannard J, Martin R. Negative pressure wound therapy for management of the surgical incision in orthopaedic surgery: a review of evidence and mechanisms for an emerging indication. *Bone Joint Res* 2013; 2: 276–84.
10. Karlakki S, Hamad AK, Whittall C, Graham NM, Banerjee RD, Kuiper JH. Incisional negative pressure wound therapy dressings (iNPWTd) in routine primary hip and knee replacements—a randomised controlled trial. *Bone Joint Res* 2016; 5: 328–37.
11. Husereau D, Drummond M, Petrou S, Carswell C, Moher D, Greenberg D, Augustovski F, Briggs AH, Mauskopf J, Loder E.

- On behalf of the CHEERS Task Force. Consolidated Health Economic Evaluation Reporting Standards (CHEERS) statement. *Value in Health* 2013;16: 231–50.
12. National Institute for Health and Clinical Excellence. *Prevention and treatment of surgical site infection CG74*. London: National Institute for Health and Clinical Excellence, 2008.
  13. Shmueli A. Subjective health status and health values in the general population. *Med Decis Making* 1999; 19: 122–27.
  14. NHS Electronic Drug Tariff, 2016. Available at [http://www.drugtariff.nhsbsa.nhs.uk/#/00330394-DD/DD00329920/Part\\_VIIIA\\_products\\_C](http://www.drugtariff.nhsbsa.nhs.uk/#/00330394-DD/DD00329920/Part_VIIIA_products_C) (accessed May 13, 2016).
  15. Department of Health, NHS reference costs 2014 to 2015. Available at <https://www.gov.uk/government/publications/nhs-reference-costs-2014-to-2015> (accessed May 13, 2016).
  16. Curtis L, Burns A. Unit Costs of Health and Social Care 2015, *Personal social services research unit*, Canterbury: University of Kent, 2015.
  17. Fenwick E, Byford S. A guide to cost-effectiveness acceptability curves. *Br J Psychiatr* 2005; 187: 106–8.
  18. Public Health England. *Surveillance of surgical site infections in NHS hospitals in England, 2014/15*. London: Public Health England, 2015. Available at <https://www.gov.uk/phe> (accessed July 28, 2016).
  19. Pellino G, Sciaudone G, Candilio G, Campitiello F, Selvaggi F, Canonico S. Effects of a new pocket device for negative pressure wound therapy on surgical wounds of patients affected with Crohn's disease: a pilot trial. *Surg Innov* 2014; 21: 204–212. doi: 10.1177/1553350613496906.
  20. Welte R, Feenstra T, Jager H, Leidl R. A decision chart for assessing and improving the transferability of economic evaluation results between countries. *Pharmacoeconomics* 2004; 22: 857–76.
  21. Tanner J, Khan D, Aplin C, Ball J, Thomas M, Bankart J. Post-discharge surveillance to identify colorectal surgical site infection rates and related costs. *J Hosp Infect* 2009; 72: 243–250.

Copyright of Wound Repair & Regeneration is the property of Wiley-Blackwell and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.